OASYS Laser Radar Characterization of Natural and Manmade Terrestrial Features

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ABSTRACT

Performance of the Northrop Grumman Obstacle Avoidance Laser Radar System (OASYS) has been characterized against various terrestrial targets. OASYS is capable of discriminating and identifying objects from a complementary background as well as producing high-resolution laser radar imagery. Its primary function alerts pilots to obstacles in a helicopter flight path; thus allowing evasive maneuvers to be performed to avoid collision. Primary obstacles encountered are: 1) wires; 2) trees; 3) transmission towers; 4) vertical poles; 5) structures, and; 6) terrain. Of these, wires are the most difficult to detect due to their small cross section. A simple, but very effective object identification algorithm is utilized which unerringly communicates large volumes of detected object data to the pilot, or to the recording computer for later analysis. In the program reported here, laser radar images of various terrestrial objects were obtained and their properties measured. In this manner a database of object signatures, cross-sections, and images is obtained. These objects include: 1) wires of various diameter and reflectivity; 2) trees and vegetation; 3) large and small vertical objects including transmission towers and poles; 4) buildings and structures, and 5) various terrain types.

Keywords: Laser Radar, LADAR, Obstacle Avoidance, Terrain Imaging, Wire Detection

1. INTRODUCTION

The Northrop Grumman Obstacle Avoidance System (OASYS) is currently one of the most advanced laser-based helicopter obstacle avoidance system flying in the world today. Begun as a joint Northrop/SPARTA/United States Army development program in 1990, the system employs low-cost, near-infrared diode laser technology configured as an imaging laser radar to scan the area ahead of the helicopter. Pulsing at a 100 kHz repetition rate, the individual returns from objects in the flight path form a laser radar image of the flight path ahead of the helicopter and, using information calculated from the helicopter trajectory, the system identifies a safe region in which the aircraft may maneuver [1].

High-resolution laser radar images of various terrestrial objects were obtained and their properties measured by mounting OASYS on a ground vehicle (Land Rover) and transporting it to various locations.

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In this manner a database of object signatures, cross-sections, and images is obtained. These objects include: 1) wires of various diameter and reflectivity; 2) trees and vegetation; 3) large and small vertical objects including transmission towers and poles; 4) buildings and structures, and 5) various terrain types. OASYS can discriminate and identify objects against a complementary background. This allows realization of objects that cannot otherwise be seen using other active and passive detection systems.

The results reported here comprise a multi-stage effort to characterize OASYS performance against different types of natural and manmade terrestrial features. Every object inside a helicopter flight path may be considered an obstacle and these obstacles have a wide variation in type and form. There are numerous objects present inside a helicopter flight path and it is important to determine how these objects are embedded in the landscape.

Several stages of data acquisition were performed and included: 1) OASYS laboratory testing, vehicle installation, and vehicle testing; 2) stationary data acquisition; 3) 3-D database development; 4) moving vehicle data acquisition, and; 5) data reduction and analysis.

The overall goals of the effort were to:

- Investigate the data acquisition capability of an imaging laser radar.
- Understand the nature of the acquired data and its potential application to collision avoidance and intelligent flight path guidance.
- Understand how active sensor data may be processed to develop high-resolution obstacle databases for flight (route) planning.
- Perform flight test risk reduction by understanding system integration aspects.
- Assess OASYS adverse weather capability.

2. OBSTACLE DETECTION

Obstacles may be classified into three categories: 1) terrain; 2) structures, and; 3) wires. Those obstacles classified as terrain may include ground, hills, valleys, steep slopes, sand dunes, and other natural and manmade landscape features. Typically, helicopters flying nape-of-the-earth flight paths must rely upon altimeter flight data to indicate position above the ground, and pilot visual data to indicate what is present in the flight path ahead. The altimeter only provides information about the position of the helicopter above the ground beneath its flight path and provides no information about obstacles present in the flight path ahead. The pilot must rely upon visual data for this information. In the presence of hills or steep slopes, for instance, the pilot would have to rely solely upon visual reference to determine the presence of obstacles. At night the task of seeing any type of obstacle becomes significantly compounded.

The second category of obstacles is structures, and may be classified as both natural and manmade objects. Structures may include trees, radio transmission towers, power line pylons, telephone poles, houses, and buildings. Again, the only indication of the presence of these objects is visual and hence they are difficult to detect.

The third category of obstacles is wires, which are the most difficult objects to detect because of their small geometric cross section. It is for this reason that wire detection usually sets the baseline performance of any obstacle avoidance system. A fundamental parameter for determining system performance is the response of typical power transmission wires to laser illumination. The system performance evaluation needs to consider the reflectivity of real wires as a function of polarization, angle of incidence, and whether the wire is wet or dry.

3. SYSTEM WAVELENGTH

OASYS operating wavelength is based upon several conditions, including wet and dry reflectivity of wires, atmospheric transmission, laser diode wavelength, power availability, operational lifetime, and eye safety. Extensive measurements of wire reflectivity were performed at 0.82 µm and 1.5 µm as a function of polarization and angle of incidence [2,3]. Averaged over all incident angles, the circular polarization reflectivity is 81% of the reflectivity of the vertical-vertical case. Thus, for a system using orthogonal polarization to separate transmit and receive beams, circular polarization is the best choice.

Wire reflectivity as a function of angle of incidence was examined for 1.06 µm, 1.54 µm, and 10.6 µm wavelengths, for both wet and dry wire conditions. At 1.06 µm there is little difference in reflectivity between wet and dry wires; the reason for this behavior is shown in Figure 1 [4]. Here, a five order of magnitude variation is seen in the absorption of water between 0.8 µm and 10.6 µm. Thus, with the assumption that a wet wire has a water layer 0.01 mm thick, the one-way transmission at 1.06 µm and at 10.6 µm is 0.999 and 4.5×10^{-5}, respectively. Next, at 1.54 µm, there is a slight indication of specularity due to the wire being wet. Finally, at 10.6 µm, the reflection from the wet wire is clearly specular; the reflectivity at normal incidence is reduced by an order of magnitude from that of a dry wire. Hence, at longer wavelengths the predominant reflection originates from the water surface which is specular, and the wire contributes very little to the overall reflection. At shorter wavelengths reflections are present from both the water on the surface of the wire and the underlying wire itself. This suggests that a wavelength of the order of 1 micron might be optimum for all weather performance.

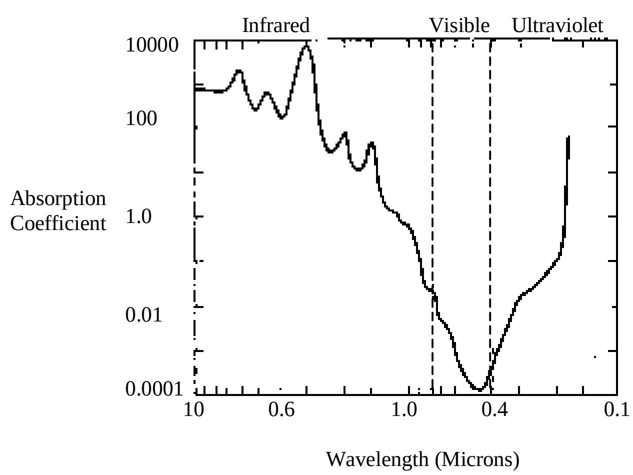

Figure 1. Absorption of radiation by sea water

Atmospheric transmission is another consideration for selection of the OASYS wavelength. Figure 2 is a LOWTRAN 7 atmospheric transmission plot computed at a spectral resolution of 5 cm^{-1}; adequate for diode lasers with bandwidths of 3 nm (42 cm^{-1}). Mie scattering from atmospheric aerosols varies with wavelength and aerosol type but favors a longer wavelength selection.

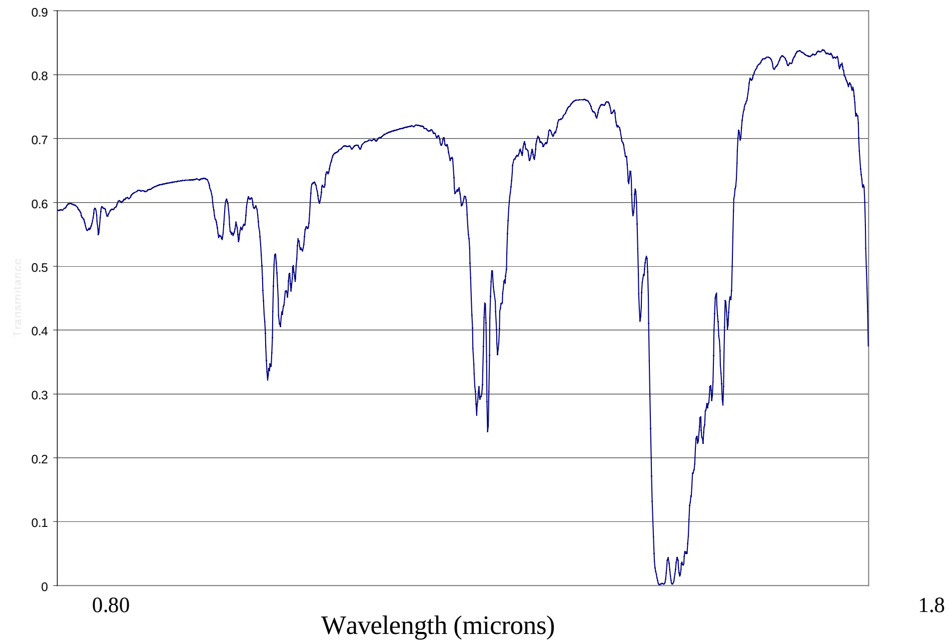

Figure 2. LOWTRAN7 atmospheric transmission (1 km horizontal path and 5 km visibility)

Taking all these factors into account, the wavelength was chosen to be in the near infra-red.

A high brightness laser-diode concept is utilized in OASYS which allows the collimation of the emissions from several laser elements;; OASYS uses two laser elements and a common collector. This approach allows multiple laser diodes to be used in the illuminating beam and decreases the critical laser output power per unit length of each laser element. The result is increased output power and improved laser lifetime. A single aperture system is dictated by constraints that define system size and weight limitations, unaided and aided ocular viewing hazards, and the requirement for reasonable range performance. Additionally, isolation of the receiver from the transmitted laser pulse dictates the use of orthogonal transmit and receive polarization to increase the separation of the two paths.

4. Field of View and Regard

The field-of-view (FOV) and field-of-regard (FOR) are critical OASYS design parameters. Considerations for these two parameters are: 1) the FOR should be large enough to detect obstacles that would interfere with safe flight, assuming reasonable future maneuvers of the helicopter; 2) the instantaneous FOV establishes the system object resolution and should be capable of resolving objects to within 7 m of other objects in either range or elevation; 3) the scan rate should be rapid enough to detect objects just missed by the previous scan and before they become critical objects; 4) gaps between scan lines should be minimal to insure that the probability of losing an object in the gap is low (it is assumed that adjacent spots overlap so no gaps exist along each scan line), and; 5) there are two rotational degrees of freedom corresponding to those required to scan the FOR.

The FOR must provide a safe region during the period of time between successive illuminations of the edge of the beam. Thus, a scanner operating in one direction and then back in the reverse direction corresponds to two frame-time intervals. Hence, the scanner must scan a FOR large enough for a two second safe region. Figure 3 depicts a safe region for a horizontal scan of $\pm 15^{o}$ for an aircraft flying at 50 m per second (98 knots). The heavy lines are the path of the aircraft if it initiates a 2-G turn with a heading acceleration of

20^{o} per second at time t=0. The obstacle that is just outside the safe region will be scanned 1.7 seconds later for a system fixed to the aircraft; if the pilot immediately reverses his turn with the same angular heading acceleration, he will just miss the obstacle. Thus, $\pm 15^{o}$ horizontal FOV is the minimum requirement for a system that is fixed to an aircraft.

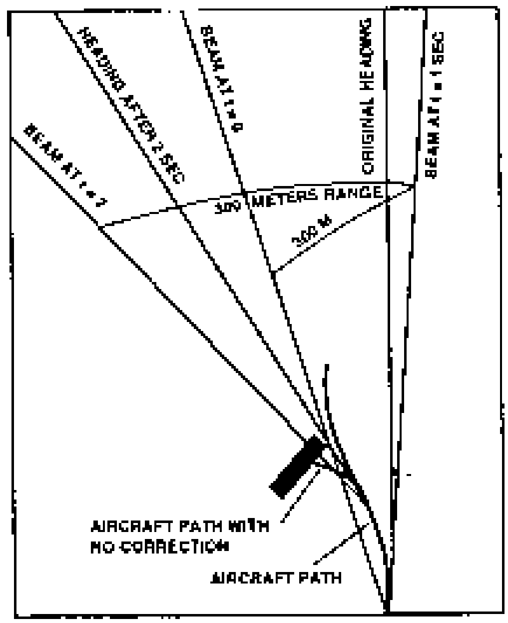

Figure 3. Safe regions for horizontal scan of 30° (min) and 50-m/sec velocity

Establishment of the instantaneous FOV is based upon the ability to: 1) separate wires 7 m above a tree line; 2) provide sufficient coverage to leave no gaps in the vertical direction, and; 3) to have adequate SNR to detect wires at the required ranges. The principal range limitation of the OASYS is dictated by the laser diode (available peak power, pulse repetition frequency, and eye hazard). The current laser has 120 watts peak power and a maximum pulse repetition frequency of 100,000 pulses per second, and the system is eye safe at the aperture. The minimum angular instantaneous FOV to just avoid vertical gaps is given by:

$$\alpha = 2\pi \frac{rps}{f} \sin\gamma, \qquad \text{Equation 1}$$

where *rps* are the scanner revolutions per second, *f* is the number of laser pulses per second, and γ is the scanner circular deviation. Thus, with a desired vertical FOR of 25^{o}, γ becomes 12.5^{o}.

With any active system, the objective is to address as much solid angle per unit time as possible; this implies using the highest achievable pulse rate one, in this case 100,000 pulses per second. Therefore, Equation 1 sets a relationship between the vertical angular FOV and the rotational rate, in revolutions per second (rps) of the scanner. The vertical angular FOV is determined from the system SNR and the transmitted beam divergence. Since the system desired vertical angular FOV is 1.5 mrad, the rps value must be 110.

The receiver vertical angular FOV must be sufficiently large to capture any returned laser energy yet small enough to avoid excess solar radiation induced background noise. In any scanning system, there is

a time delay between the laser emission pulse and the return laser pulse. During this interval the scanning system has rotated and is now looking in a different direction. Thus, in focal plane coordinates, this time delay offsets the return energy. This delay, δ, is given by:

$$\delta = 4\pi \times rps \times \sin\gamma \frac{r}{c}, \qquad \text{Equation 2}$$

where r is the one way range and c is the velocity of light. At a range of 400 m, δ is 0.4 mrad. This now sets the vertical angular FOV of the receiver at 1.9 mrad (the angular extent of the transmitted beam) + 2 x 0.4 mrad (since the scan moves in two directions, the delay in both directions must be included).

At night, the horizontal extents of the angular FOV are not critical against small horizontal wires, the worst case target. The receiver FOV must be sufficiently large to account for this delay as any further increase in horizontal FOV will decrease the fluence incident upon the wire. This will not change the amount of laser energy incident upon the wire, and, a change in the horizontal FOV will not affect the nighttime performance. However, during the day, the solar background noise entering the system must be limited; thus the solid angle must be minimized.

Figure 4 depicts the scan pattern of a 100 kHz diode laser emitting a 1.5 mrad beam at a range of 400 m. This scan pattern is quite efficient for the OASYS FOR which is twice as wide as it is high. The region where scans overlap, the dark almost triangular sections, comprise only 12% of the solid angle scanned. Of this overlap, the upper triangle provides a more frequent update to the region ahead and above the helicopter's flight path.

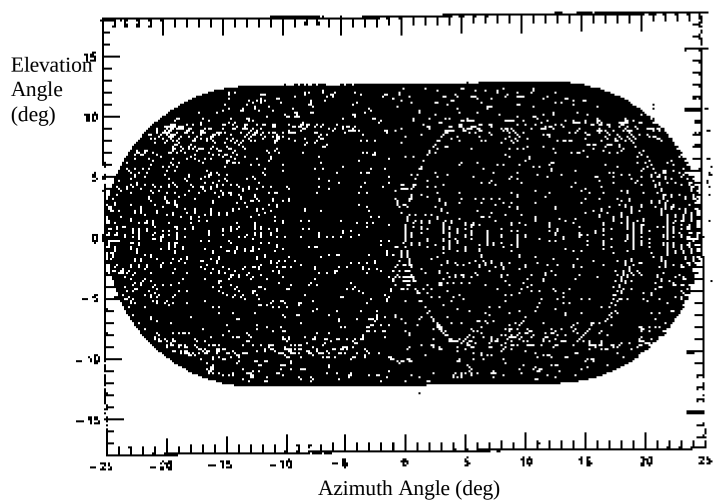

Figure 4. HOE scan pattern at 110 Hz showing 25% laser pulse overlap at 400 m

Once objects have been detected and processed this information must be made known to the pilot in a simple, instantly understandable fashion. The most sophisticated sensor, one that meets all performance requirements, will fail to achieve acceptance without a proper helicopter-pilot interface. The OASYS Window-of-Safety symbology approach was developed and has achieved pilot acceptance. This symbology is displayed over the normal, constantly monitored, pilot display. As a last resort, only if the pilot fails to respond to the cued information, will an audible warning, in the form of a voice synthesizer, warn the pilot of the impending obstacle danger. For visually coupled systems this information is combined with FLIR imagery and the symbology displayed on the Integrated Helmet and Display Sight

System (IHADSS) helmet mounted display. For aircraft utilizing ANVIS goggles the OASYS symbology is overlaid on the goggle imagery utilizing a head up display (HUD). OASYS symbology can be overlaid on practically any visual display medium.

Figure 5 shows an actual frame from an OASYS display. A notch in a ridgeline is depicted with the aircraft flying through this area. Also shown is the standard pilot symbology consisting of heading, airspeed, and altitude. Superimposed upon this image is the OASYS Window-of-Safety which provides a demarcation between the safe and the unsafe region. A diamond symbol is added which informs the pilot of his location within the Window-of-Safety. This symbology approach simply requires the pilot to keep the diamond symbol above the demarcation line at all times, thus, he will be assured of avoiding any obstacle.

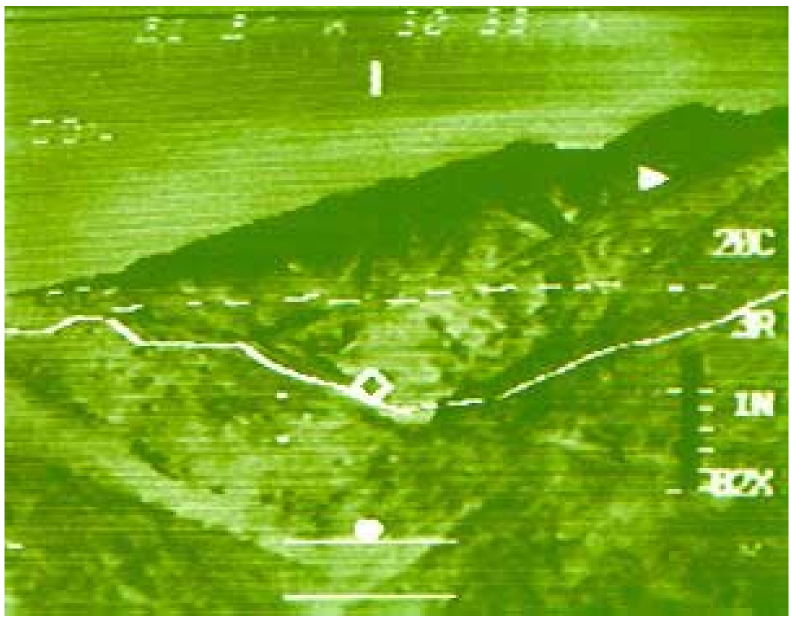

Figure 5. OASYS pilot display

5. Ground Trial Results

Data were acquired at various sites within the greater Salisbury area. Sites were selected to best represent those scenarios that a pilot may face when confronted with low altitude, level flight. In this capacity, areas were selected where obstacles would appear against a complimentary background, thus rendering them very difficult to observe with the unaided eye. Data was gathered in various weather conditions and included: 1) full sun; 2) fog; 3) night; 4) rain, and; 5) snow. Additionally, in one instance, the system was oriented to detect power lines in front of the sun that was nearly at the horizon.

5.1 Haxton Down Wood

This site provided views of receding woods and Sidbury Hill. Tree lines were observed from 60 m to 530 m, and from 500 m to 650 m with Sidbury Hill at 1400 m, beyond the 635 m maximum range of OASYS. A photographic image is shown in Figure 6 with the OASYS LADAR image in Figure 7.

Figure 6. Haxton Down Wood photograph

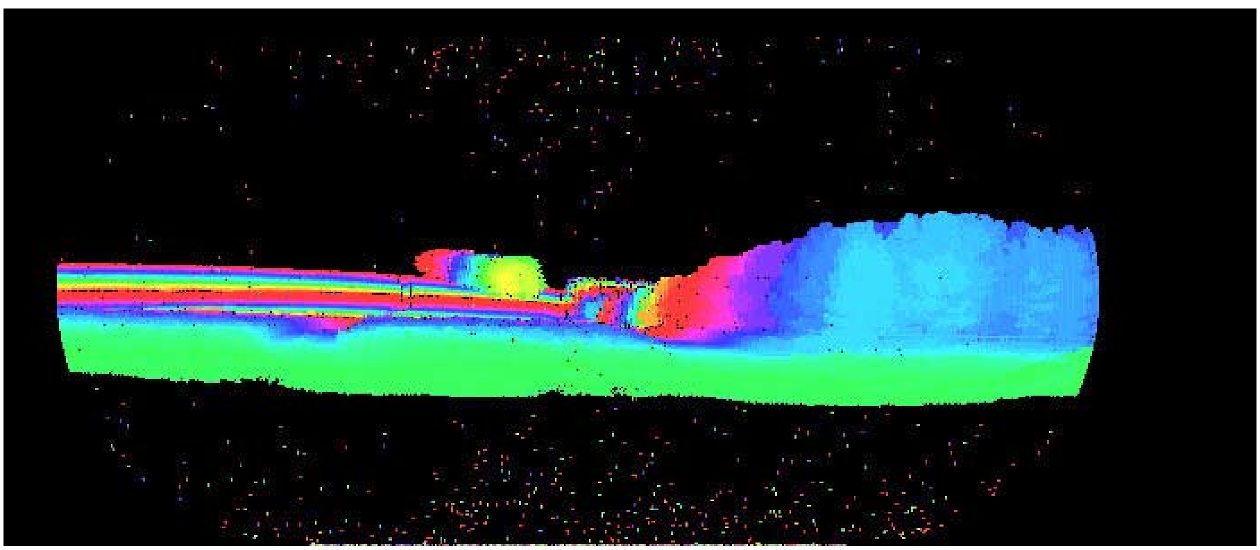

Figure 7. Haxton Down Wood LADAR image

5.2 Barrow Hill

This area provided several points by the side of a secondary road, with views looking into a low valley. Angled wires and wood lines ranged from 200 m to 700 m. In Figure 8, the photographic image, a pole is visible to the left of center, but wires are not visible. These wires are clearly visible in the LADAR image Figure 9. It is also interesting to note that wheel ruts from farm machinery are visible in the LADAR image. Figure 10 shows a distant tree line at more than 600 m. There is a clearing to the right of the left hand group of trees that may present an escape route for a low flying helicopter. In the LADAR image, Figure 11, one can see the telegraph pole and wires just to the right of these trees. It is interesting to note that the yellow blobs in the LADAR image are the sheep.

Figure 8. Barrow Hill Low Valley Photograph

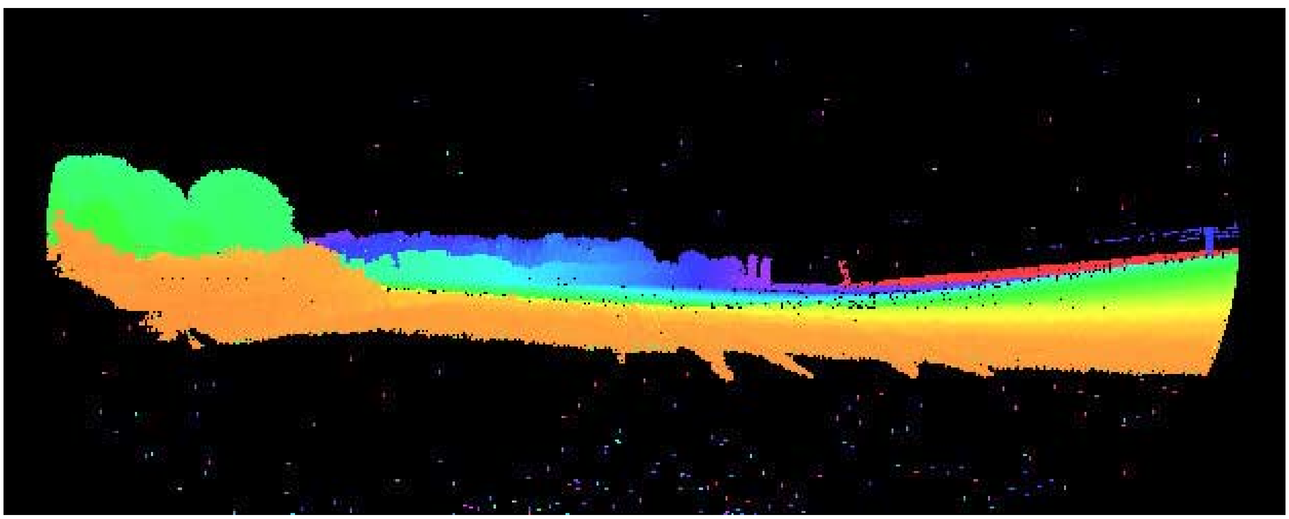

Figure 9. Barrow Hill Low Valley LADAR Image

Figure 10. Barrow Hill tree line with clearing

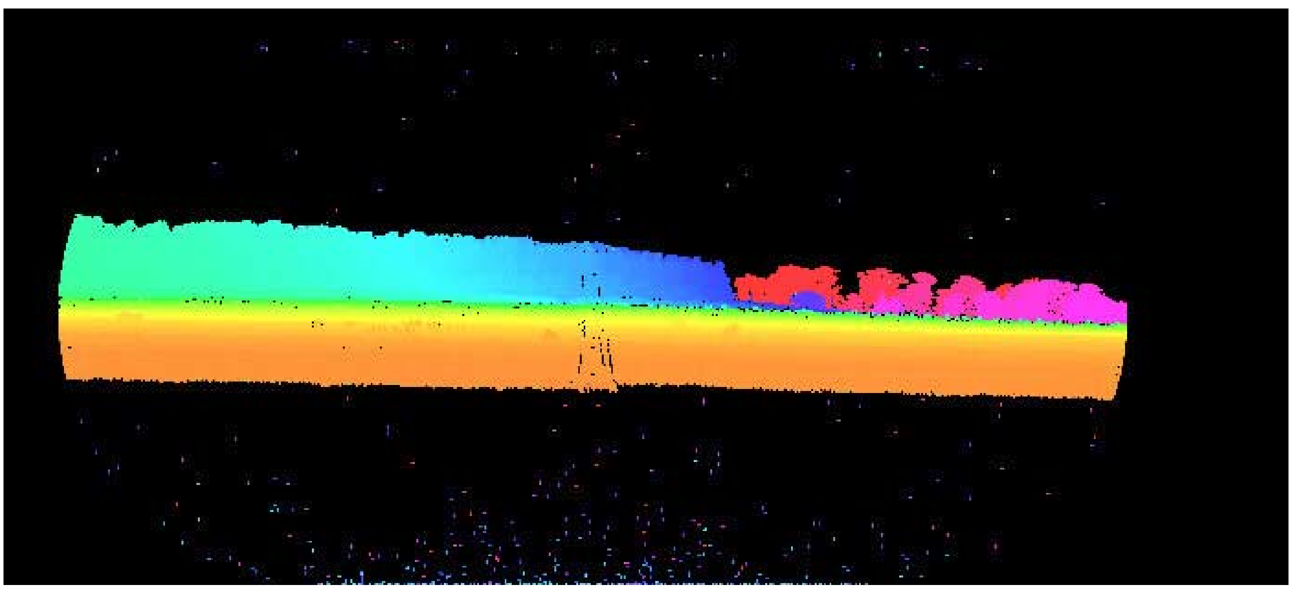

Figure 11. Barrow Hill tree line with clearing LADAR image

5.3 MoD Sportsground

The MoD Sportsground car park offered views toward Beacon Hill and Boscombe Down. Short range objects included pylons, power cables, woods, single trees, and masts. Figure 12 shows a relatively large pylon; wires are not visible. In the LADAR image, Figure 13, the wires are clearly visible. Figure 14 shows the sum low on the horizon, clearly interfering with the ability to detect pylons and power lines. In Figure 15, the LADAR image, these critical features are clearly visible. Figure 16 shows the same scene

through dense fog; most features are not visible. In the LADAR image, Figure 17, the scene is vastly improved.

Figure 12. Tree Line with large pylon

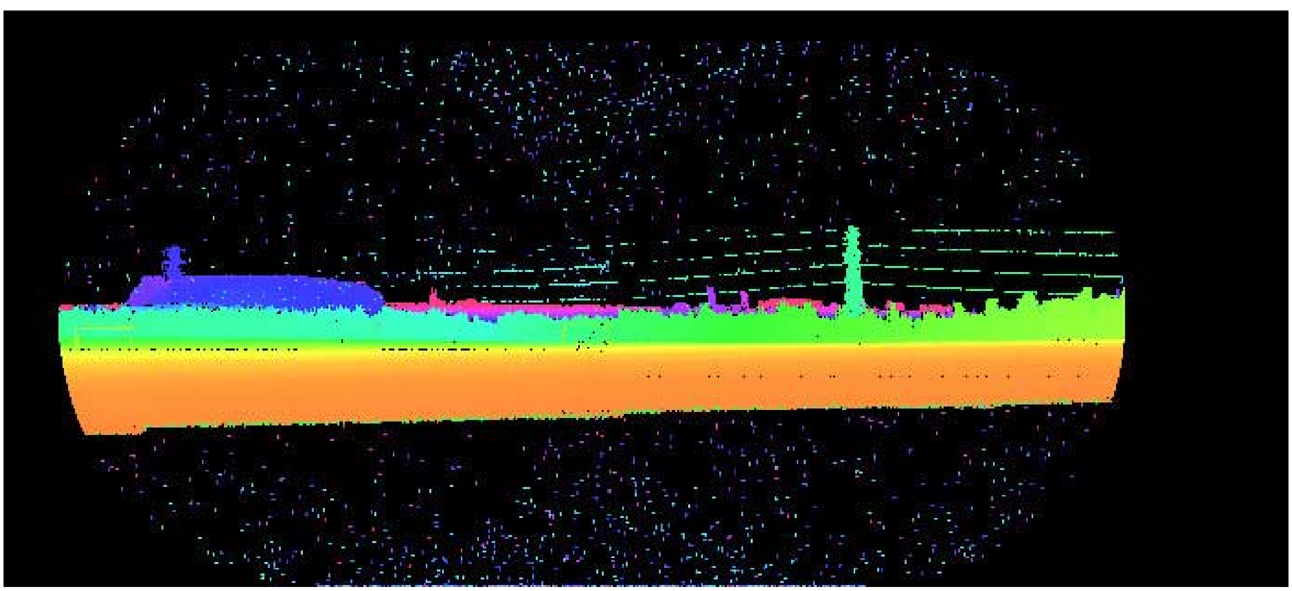

Figure 13. LADAR Image of tree line with large pylon

Figure 14. Scene obscured by sun on horizon

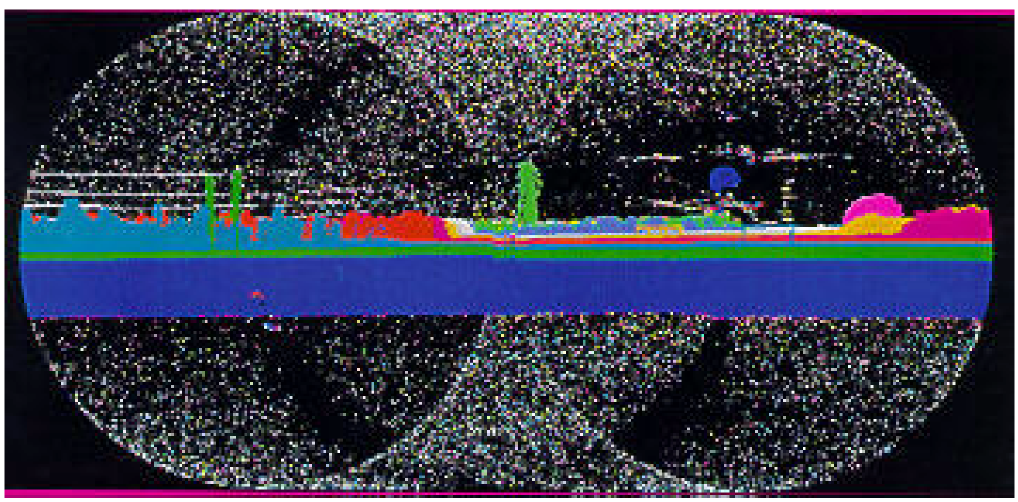

Figure 15. LADAR image showing pylons, wires, and trees clearly visible.

Figure 16. Scene obscured by fog.

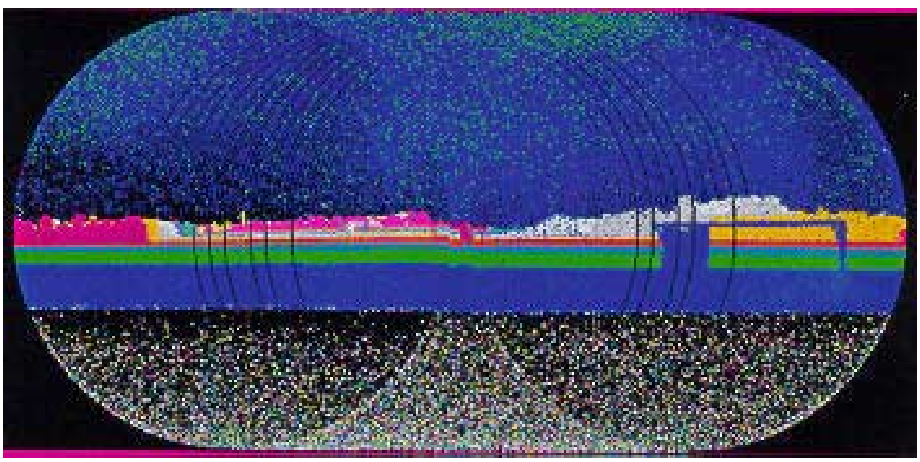

Figure 17. LADAR image through fog showing details in far-field.

6. Conclusion

Performance of the Northrop Grumman Obstacle Avoidance Laser Radar System (OASYS) has been characterized against various terrestrial targets. The ability of OASYS to discriminate and identifying objects from a complementary background as well as producing high-resolution laser radar imagery has been shown. While OASYS primary function is to alert pilots to obstacles in a helicopter flight path it provides significant additional capability as an imaging laser radar system. Northrop Grumman's OASYS is one of the most advanced helicopter obstacle avoidance laser radar in the world today and these joint Northrop Grumman/DERA ground trials are the most extensive undertaking of data acquisition for the purpose of ascertaining imaging laser radar performance against a variety of targets and performed under varying weather conditions.

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